

JAPAN'S RESEARCH ON PARTICLE CLOUDS AND SPRAYS

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Introduction

Most of energy used by us is generated by combustion of liquid and solid fuels. These fuels are burned in the combustors mainly as liquid sprays and pulverized solid, respectively. Knowledge of the combustion process in the combustors is needed to achieve proper designs that have stable operation, high efficiency, and low emission levels. However, current understanding on liquid and solid particle cloud combustion is far from complete.

If the combustion experiments for these fuels are performed under normal gravity field, some experimental difficulties are encountered. These are

- Particles are falling by the gravity force. It is impossible to stop the particles in the air.
- Falling speeds of particles are different each other, which depend on the particle size.
- Flame is lifted up and deformed by the buoyancy force.
- Natural convection makes the flow field to be more complex.

Since these experimental difficulties are attributable to the gravity force, the microgravity field can eliminate the above problems. It means that the flame propagation experiments in a static homogeneous liquid and solid particle clouds can be carried out under microgravity field. It will provide many informations for basic questions related to combustion processes of particle clouds and sprays.

In Japan, flame propagation processes in the combustible liquid and solid particle clouds have been studied experimentally by using the microgravity field generated by the 4.5-second dropshaft, 10-second dropshaft, and parabolic flight. They are the studies on flame propagations in a homogeneous liquid particle cloud, in a mixture of liquid particles/gas fuel/air, in a PMMA particle cloud, and in a pulverized coal particle cloud. This presentation describes recent results of these studies.

SpraysFlame propagation in a homogeneous liquid droplet cloud:

Purpose of this study is to explore the flame propagation process in a liquid droplet cloud at elevated pressures. This study is supported by Science and Technology Agency (STA) and National Space Development Agency (NASDA). Since the no-movement liquid droplet cloud with mono-size and mono-disperse is suitable for the experiments, the droplet cloud generation system has been studied firstly. Sato and Nomura have been studying the condensation method to generate the homogeneous droplet cloud (Ref. 1). Figure 1 shows a schematic diagram of the experimental apparatus. If the pressure of the

saturated fuel vapor and air mixture is decreased adiabatically, the temperature of the mixture decreases and the liquid droplets are generated in the mixture. If this system is operated under normal gravity condition, the generated droplets fall as rain by the gravity force. The microgravity experiments were performed by the parabolic flight of a small jet airplane named MU-300 and the 4.5-dropshaft, which was constructed recently at Toki, Gifu. Figure 2 shows the photograph of the generated ethanol droplets in the ethanol vapor/nitrogen mixture. In the photograph, the black line is the thermocouple with 30 micron meter diameter. The droplets with about 10 micron meter diameter are formed homogeneously. Figure 3 shows the droplet diameter distribution. Nearly homogeneous droplet cloud is formed.

The flame propagation experiments will be started from June, 1995. The flame propagation behavior and the droplet behavior will be observed by the high-speed color video camera, interferometer, and the PIV system. In August 1996, the experiments will be performed in the longer microgravity field obtained by the sounding rocket TR-1A.

Flame propagation in a fuel droplets/gas fuel/air mixture:

Purpose of this study is to observe the flame propagation behavior in a liquid droplets/gas fuel/air mixture. This study is carried out by Hiroyasu et al. (Ref. 2) and supported by New Energy and Industrial Technology Development Organization (NEDO) under controlled by Ministry of International Trade and Industries (MITI). Figure 4 shows the experimental apparatus. The propane/air mixture is filled in the flame tube with rectangular section of 50 x 50 mm and then the kerosene is injected in it. The microgravity experiments were performed by 10-second dropshaft. The most of microgravity time was used for making the static homogeneous droplet cloud. The mixture was ignited by the electric spark. Figure 5 shows the flame propagation distance with time. The total equivalence ratio is 0.8 and the propane gas ratios in the total equivalence ratio R_g are 0.7 and 0.6. When R_g is 0.7, since the propane/air mixture is in the flammability limits, the flame propagates in the premixed gas and the droplets burns after the flame propagation. When R_g is 0.6, since the mixture is out of the flammability limits, the flame does not propagate in the premixed gas. The flame propagates from a droplet to the other one slowly. Figure 6 shows the flame propagation behavior of $R_g = 0.6$.

Solid particle clouds

Flame propagation in a PMMA particle cloud:

Purpose of this study is to explore the flame propagation mechanism in a liquid droplet cloud with lower volatility and in a solid particle cloud with high volatility. PMMA is suitable to the experiments because the round mono-size particles are easily obtained and its burning behavior is simple and well known. This research is carried out by Niioka et al. (Ref. 3) and is supported by NEDO. Figure 7 shows the experimental apparatus. The PMMA particles are fed by the fluidized bed and send to the flame tube with the

diameter of 38 mm. The microgravity experiments are performed by 10-second dropshaft. Most of the microgravity time is used to obtain the static mono-dispersed particle cloud in the flame tube. Figure 8 shows the effects of the equivalence ratio on the flame velocity. The flame velocity has a maximum at a certain value of the equivalence ratio over one. If the particle size is increased, the maximum flame velocity decreases and the equivalence ratio at which the peak appears increases. Figure 9 shows the effects of methane adding in the PMMA particle cloud. Adding one percent of methane changes the flame speed remarkably. But, more adding changes not so much.

Flame propagation in a pulverized coal particle cloud:

Purpose of this study is to obtain the flame propagation velocity in a pulverized coal particle cloud and the parameters affecting it. This study is carried out by Ito, Kitano, and Sato (Ref. 4) and supported by NEDO. Figure 10 shows the experimental apparatus. The microgravity experiments are performed by the 10-second dropshaft. The pulverized coal, which is under 200 mesh (about 70 micron meter diameter), is ejected into the burning region by the static electric force under microgravity. After about 5 second, the coal particles are homogeneously dispersed and stop. The coal particle cloud is ignited by a nichrome-wire at the center. The spherical flame propagation is observed after ignition as shown in Figure 11. The tests were performed mainly for the Taiheiyō coal, which is a kind of bituminous coal. Figure 12 shows the effects of the coal concentration on the flame speed. In this experimental range, the flame speed increases as the concentration is increased. The inert gas, nitrogen, in the air was replaced by the carbon dioxide and the argon, and then the effects of these gases were examined. The flame speed in the carbon dioxide mixture is lower than the others. The gas analysis and the particle analysis just after burning showed that the burning temperature for the carbon dioxide mixture is lower than the others. In these studies, the effects of the oxygen concentration, the ambient pressure, and the kind of coal were studied.

References

1. Nomura, H., Sugawara, N., Meguro, T., Ujiie, Y., Masuko, K., Sato, J., and Kono, M. "Generation of static droplet cloud under microgravity conditions using a rapid expansion apparatus," Proceedings of Droptower Days '94, Bremen, Germany, 1994.
2. Hiroyasu, H., Private communication, (to be appear).
3. Kobayashi, H., Ono, N., Okuyama, Y., and Nioka, T., "Flame propagation experiment of PMMA particle cloud in a microgravity environment," Twenty-fifth International Combustion Symposium, 1995.
4. Ito, K., Fujita, O., Tagashira, T., Sakamoto, A., and Sato, J., "Utilization of a 10 second microgravity environment for the measurement of coal dust flame propagation speeds," Proceedings of Droptower Days '94, Bremen, Germany, 1994.

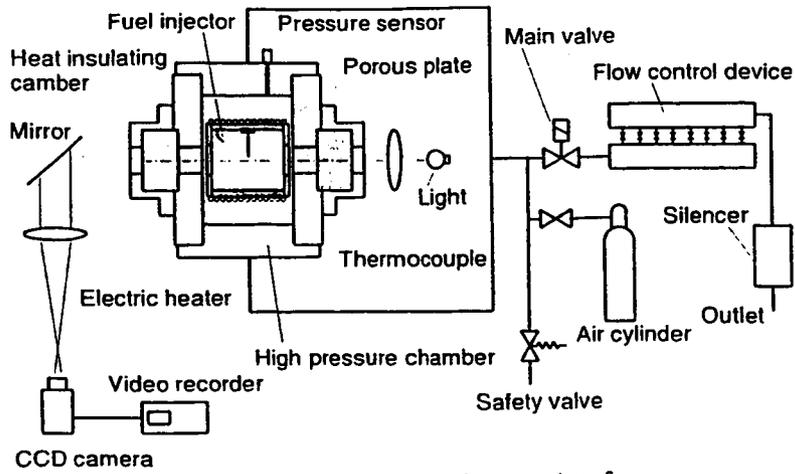


Figure 1. Experimental apparatus for Droplet cloud generation by the condensation method.



Figure 2. Ethanol droplets generated in the ethanol vapor/nitrogen mixture.

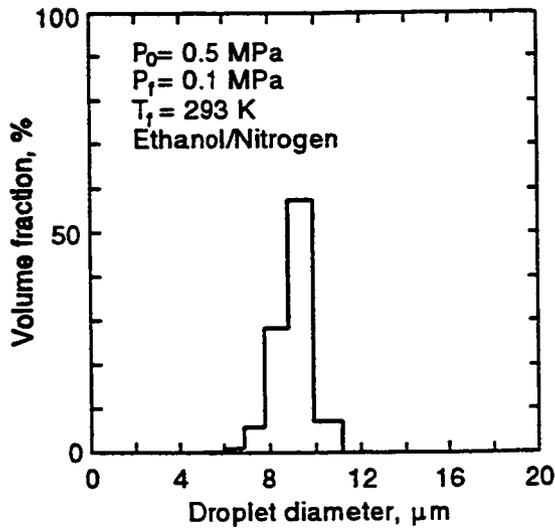


Figure 3. Distribution of the droplet diameter.

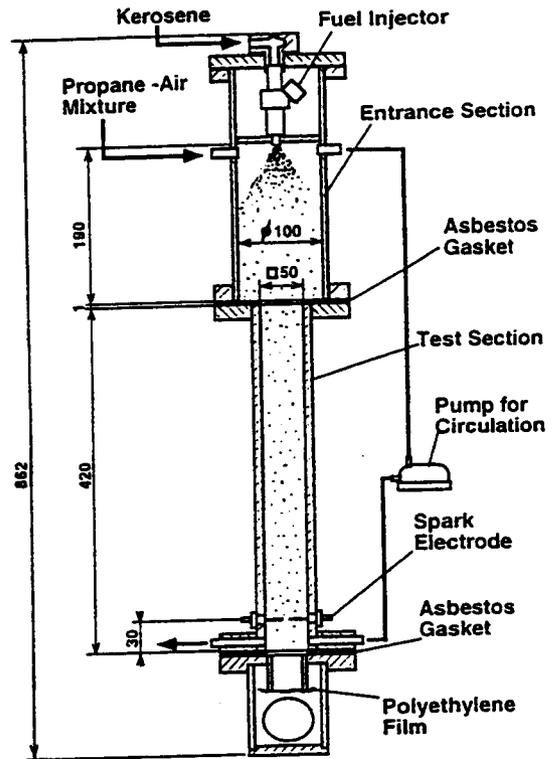


Figure 4. Experimental apparatus for flame propagation in the fuel droplets/gas fuel/air mixture.

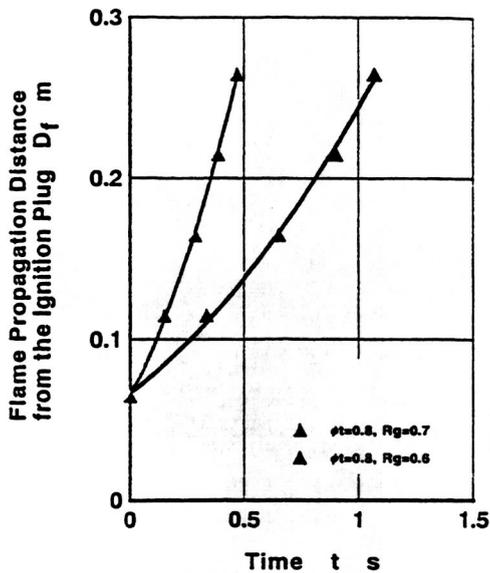


Figure 5. Flame propagation distance with time.

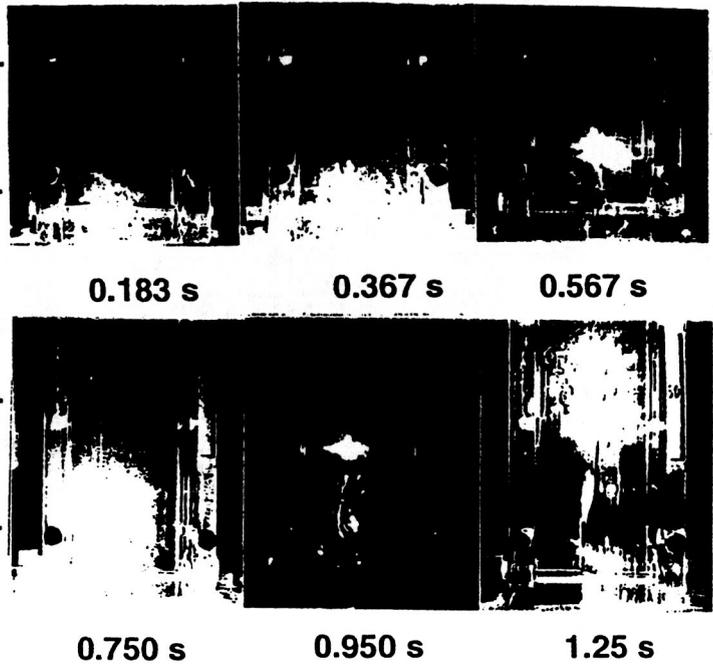


Figure 6. Flame propagation behavior in the fuel droplet/gas fuel/air mixture.

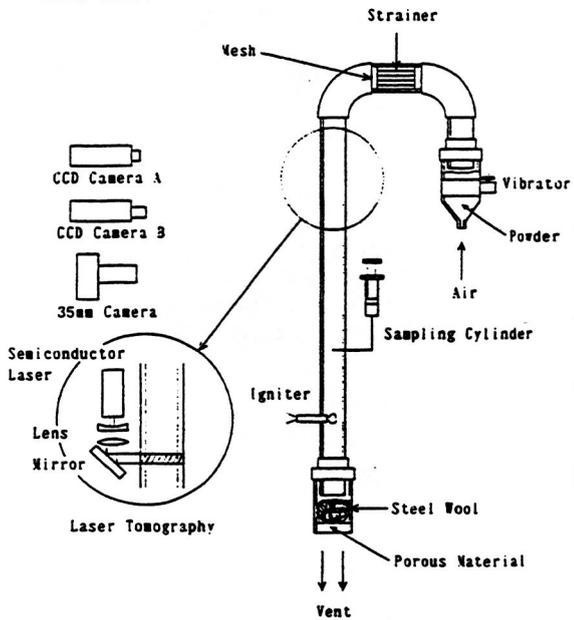


Figure 7. Experimental apparatus for flame propagation in the PMMA particle cloud.

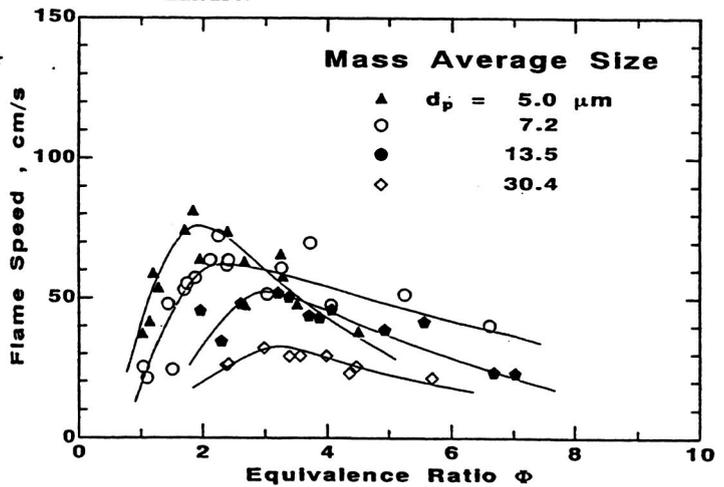


Figure 8. Effects of the equivalence ratio on the flame velocity in the PMMA particle cloud.

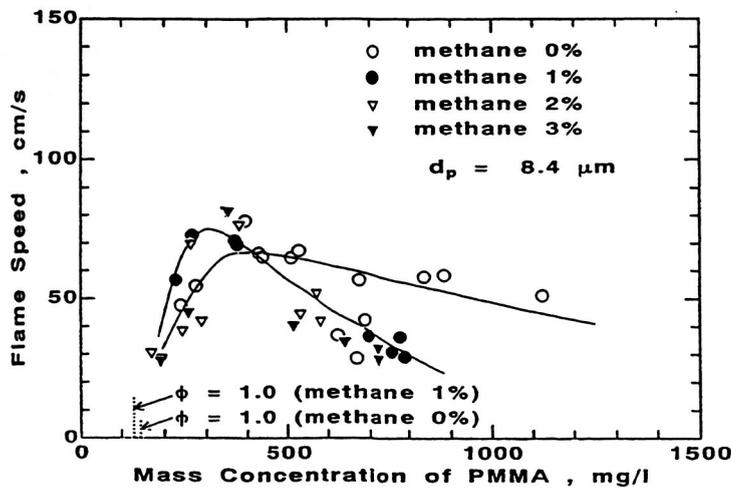


Figure 9. Effects of methane adding in the PMMA particle cloud.

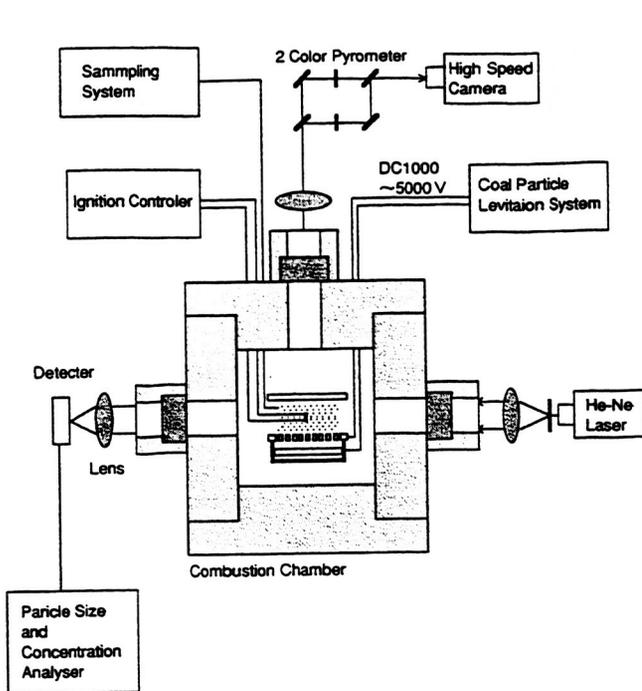


Figure 10. Experimental apparatus for flame propagation in the pulverized coal particle cloud.

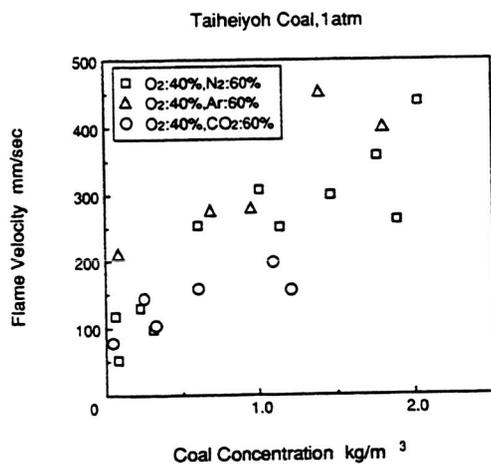


Figure 12. Effects of the coal concentration on the flame speed in the pulverized coal particle cloud.

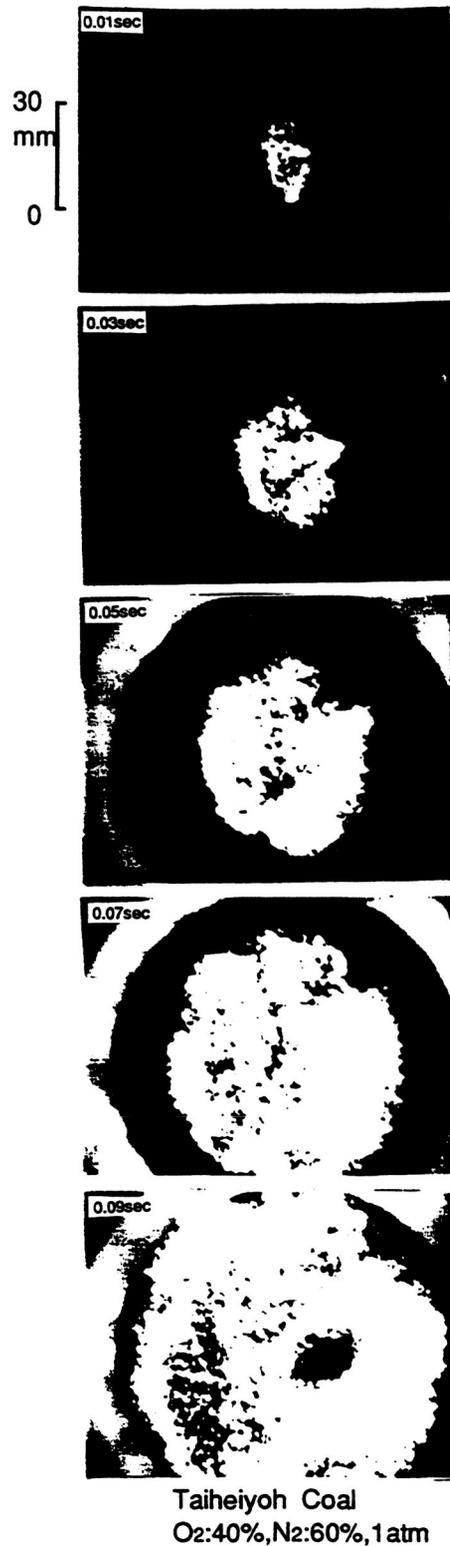


Figure 11. Flame propagation behavior in the pulverized coal particle cloud.